High-fidelity distributed acoustic sensing using optical fibers: a new tool in Geophysics

María R. Fernandez-Ruiz[1], Sonia Martins-Lopez[1], Miguel Gonzalez-Herraez[1] Hugo F. Martins[2]
[1]Departamento de Electrónica, Edificio Politécnico, Universidad de Alcalá, 28805, Alcalá de Henares, Spain.
[2]Instituto de Óptica, Consejo Superior de Investigaciones Científicas, 28006, Madrid, Spain.

Author e-mail address: hugo.martins@csic.es

Abstract

The possibility of using a pre-existent fiber optic network as Earth's nervous system to monitor deformations with high sensitivity across the world in real time is overviewed. The potential and results on the use of distributed acoustic sensing (DAS) as a tool for seismology are discussed, with emphasis on the recent technology of chirped-pulse DAS.

Keywords: Fiber Optics, Distributed Acoustic Sensing; Phase-sensitive OTDR; Chirped Pulse; Seismology;
Topic Code: Fiber optics, sensors and optical communications

Introduction

Seismic tomography allows for the study of earth's internal structure by analyzing the waves propagating in seismic events. In the pursue of high-resolution global tomography models and recognition of seismic patterns leading to potentially hazardous situations, the dense mapping of surface seismic activity over large areas across the globe is of great interest [1,2]. While nowadays a large network of seismographs exists across the globe, the majority of these are usually installed in surface areas of recognized seismic importance. The sparsity of instrumentation, particularly across Earth's oceans, limits the available information, posing an important limitation in seismology [1,2]. Since traditional seismometers record seismic activity in a single point, their massive and even deployment across the globe is not practical or even desired, as the cost and deployment issues will quick render such approach unviable.

In this context, Distributed acoustic sensing (DAS) emerges as a powerful tool for seismology. With a single interrogator, a DAS allows for the distributed measurement of strain along an optical fiber, in real-time, with high sensitivity (typically in the order of nanostrain), along tens to hundreds of kilometers, with metric spatial resolutions, thus effectively turning a conventional optical fiber cable into a dense array of strain seismometers [3]. This opens a range of possibilities that would not be available with the use of conventional point seismometers such as and 2D image mapping and operation with so called "large N" deployments [1]. Furthermore, the full compatibility with telecommunication fibers provides the ideal deployment setup, with potential for a fast implementation across an extensive network across the globe with minimal deployments costs [2].

In this work the viability of the use of a pre-existing fiber optic installation for seismic monitoring via DAS is demonstrated. A chirped-pulse phase-sensitive OTDR (CP-φOTDR) is used as the DAS sensor [3] – a recently proposed technology which allows for a linear demodulation of the strain applied along the optical fiber, without requiring the added complexity of recovering the phase of the optical signal and while avoiding the problem of fading points (existence of point with close-to-zero intensity, which translates into the occurrence of blind spots randomly placed along the fiber). An earthquake of magnitude 8.2, occurred in the Fiji Islands (2018-08-19), was detected in two different locations, separated by thousands of miles, and with different installation typology (metropolitan area and submarine) by two different DAS. The DAS results are compared with local seismometers in both cases.

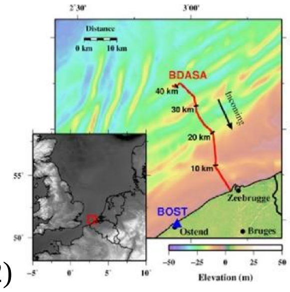
Experimental Tests

On 2018-08-19, an earthquake of magnitude 8.2, occurred in the Fiji Islands. The resulting seismic waves were recorded by two CP-φOTDR [3] (DAS sensors) in two different locations, with different fiber installations:

One DAS was placed in Pasadena (California), over 9000 km away from the epicenter. The fiber length monitored totaled 25km, consisting of previously installed fiber undergoing a nonlinear geometry through a densely populated metropolitan area (see fig.1); The other DAS was placed in Zeegrugge (Belgium), ≈16000 km away from the epicenter. The fiber length monitored totaled 40km, belonging to an underwater (depth up to ≈30m) electrical cable installation deployed in a quasi-linear geometry (see fig. 2); In both cases, the arrival of the earthquake waves was monitored by local seismometers, which was used to compared and validated the DAS results.

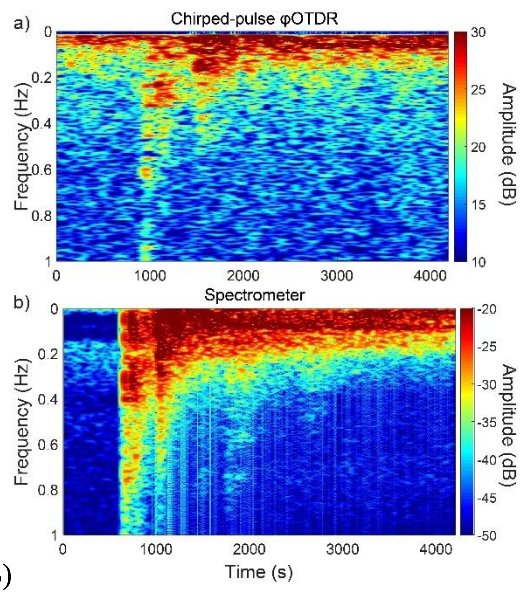
The seismic measurements are displayed in fig. 3/4, for DAS and local seismometers, showing good qualitative agreement in both locations, as a similar spectral energy distribution along time is observed. Note that while the seismometers can be expected to present better SNR (point sensor VS distributed sensor), the background acoustic noise (and not DAS intrinsic noise) is also expected to differ since the fiber and seismometer are placed in different places. Particularly for the case of Zeegrugge (fig. 4), the underwater fiber installation was exposed to noise from water waves, boats, etc.

1)

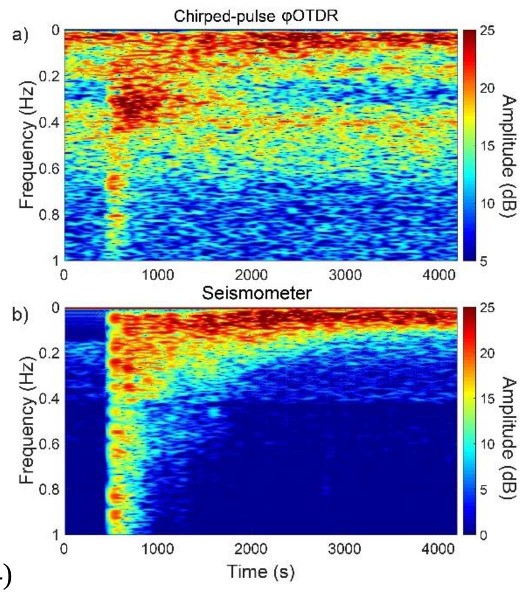


2)

Fig. 1: (a) Geometric installation of the Pasadena fiber. IU = Interrogating Unit (DAS sensor); (b) Geometric installation of the full optical fiber network in Pasadena. Fig. 2: (a)Geometric installation of the Zeebrugge fiber. In blue: Location of the seismometer with which the DAS results were compared (BOST station).



3)



4)

Fig. 3: Spectrogram of Pasadena (a) DAS sensor (sum of all channels of the last 5km of fibre); (b) Local Seismometer ; Fig. 4: Spectrogram of Zeebrugge (a) DAS sensor (sum of all channels of the last 5km of fibre); (b) Local Seismometer (BOST Station); Note: The difference in the arrival of the earthquake (time axis) is owned to a miss-synchronization of the DAS / Seismometer reference times.

Conclusions

In this work, the possibility of using optical fiber pre-installed under different scenarios as simple but effective tool to monitor seismic activity, via DAS, is demonstrated. The propagating seismic waves of an earthquake are recorded with a DAS (CP-φOTDR) in two different locations, located at ≈9000km and ≈16000km away from the epicenter, with different installation topologies (metropolitan and underwater fiber installations). The DAS signals are compared to those recorded by local seismometers with good agreement. The presented results show the high potential of the already deployed fiber optical network for its use as distributed seismometer.

Acknowledgements

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